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# *Vaccinium Macrocarpon* Ait.: Where they have been and where they are going

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## EXECUTIVE SUMMARY

Producing the perennial vine *Vaccinium Macrocarpon* Ait in greenhouses with hydroponic and possibly aquaponics production schemes we can enhance production strategies that are utilized. Moving this crop into the greenhouse allows growers to avoid management strategies that are harmful to the vines and other ecosystems. Winter flooding actually damages the plant and forces it to spend time in the spring to recover. This causes a reduction in yield from year to year; however, it is usually not noted since this practice is common among growers today and has been over the past 100 years. Moving the crop into greenhouses allows a grower to have control on the environment making this crop easier to grow. Within a controlled environment

the plant can get sufficient chilling hours while being kept above damaging temperature levels. Introducing hydroponic growing systems into the production scheme allows grower to have access to the large amount of water needed for production without drawing on public sources. The chemicals that are needed to control pest and pathogen pressures will then not be released into the aquatic ecosystem like they are today. This allows growers to use management practices that they feel comfortable with while being environmentally responsible. One of the largest issues within agriculture is the leaching of chemicals and/or nutrients that are creating harmful effects in other ecosystems. This issue is avoided with most hydroponic systems and is the future for some crop production. *Vaccinium macrocarpon* is an especially great candidate for such production since the water requirements are extremely high for the production of this crop. Efforts are needed from all avenues of plant production in order to put this plan into action. Breeders need to be actively working towards a vigorously producing vine. Further research is needed to create such a system that can be mechanized to drop the hydroponic set-up below the water level. People who have capital are needed to start the production of vines in such a manner. Engineers, breeders, researchers, and producers all have to come together to make this work.

# I. INTRODUCTION

## A. Study Species.

*Vaccinium macrocarpon* Ait (American cranberries) have many uses within the U.S. diet today. They are a staple at the Thanksgiving table alongside of turkey and mashed potatoes and gravy. *Vaccinium macrocarpon* can be use medicinally to increase antioxidant levels within the body (Sun et al. 2002). Also by consuming juice it has been known to aid in relieving minor urinary tract infections (Pérez-López, et al. 2009) because of the acidic environment that it causes (Howell 2002). However, it has recently been discovered that it is not the acidic environment that it causes making an inhabitable environment for the bacteria but the presence of Proanthocyanidins. These chemicals force that bacteria into anti-adhesion activity which helps relieve the infection (Howell 2002). A different study completed by Wu et al. (2008) has shown that food borne pathogens are sensitive to the acidic environment that cranberries are able to produce and are therefore being considered for natural, healthy preservatives. During the study four threatening food borne pathogens (*Escherichia coli* O157:H7*, Listeria monocytogenes, Salmonella Typhimurium, and Staphylococcus aureus*) were treated with 100 µl/ml cranberry concentrate. After holding temperatures at 21 and 4 °C for 24 hours, none of the target pathogens were present at detectable levels. Damage was shown to the cell walls and membranes of the pathogens (Wu et al. 2008). At its peak time of harvest, the fruiting structure (cranberry) becomes a brilliant red color that is attractive to any consumer. The name cranberry comes from the flower morphology, which resembles a sand hill cranes neck and head (hence <u>cran</u>-berry).

*Vaccinium macrocarpon* production is one of the more difficult cropping systems to sustain. People often question the use of such a system given its problems and the narrow market for such a high maintenance crop. Weed and insect pressures are difficult to overcome in this system without the use of chemical controls because of its low growing perennial vining growth habit. These chemicals are then leeched into the body of water that growers utilize to flood their fields for harvest and more economical control as well as winter protection. Environmentalists have become concerned about the impacts that such a system has on marine ecosystems that have fallen into such a cropping system (Wan 1995). When the bogs are flooded they lack the ability to filter out fertilizers and pesticides, forcing them into streams and lakes (Wan 1995). Since *V. macrocarpon* growers use public waterways to aid in their production practices most producing states have grower's water use rights written into legislature (Sandler 2008).

## B. Taxonomic Classification and Geographic Distribution in the Wild.

*Vaccinium macrocarpon* sustains itself in its native region consisting of temperate zones throughout North America extending from the Eastern Coast of the United States to the Central region (Rodriguez-Saona 2011). It also extends into some parts of south eastern Canada. Wild species were first discovered in bogs in Massachusetts where the growing media alternates between sand and high organic matter (Sandler 2008). These were naturally formed after the glaciers melting following the last ice age (Sandler 2008).

*Vaccinium macrocarpon* is a perennial vine within the Ericacaeae family that thrives in wetlands encompassing bogs, fens (calcium rich wetlands), marshes, and shores of lakes and rivers (Rodriguez-Saona 2011, Sandler 2008). This plant can produce excellent ground cover in wet situations. Table 1 describes the characteristics of the plant in detail, ranging from soil pH to flower and leaf morphology, which are key components to correctly identify this crop. A pH range of 4-5.5 is preferred for optimal growth but can tolerate more acidic conditions (Sandler 2008). The water table should be relatively close to the surface (approximately .46m) to ensure that the root systems get the correct amount of water. These plants require approximately 3 cm of water/week (Burgess 2007) making it extremely important for growers to have access to a large volume of water when growing these crops (Sandler 2008). Establishment of this crop occurs after obtaining cutting from a supplier, spreading them across the bed and mechanically inserting them into the ground. Once this is completed irrigation is required multiple times throughout the day until roots have established and new growth has begun. The leaves are simple, tiny, glossy and leathery evergreen type that stays on the plant for two years before they are shed. The three-scaled egg shaped buds produce the flower and shoot primordia in late summer of the season prior to their growth (n.a., n.d.[1]). The flowers bloom in late June/early July and resemble a sand hill cranes head. The flowers remain open for pollination for approximately three to four weeks. Since, cranberries are self-compatible a single cultivar can be planted in a bed however, this is risky as with any monoculture within agriculture. The berries begin developing soon after pollination and begin as tiny green spheres. Approximately 75-100 days after pollination occurs (depending on the cultivar) the berries should retain the stunning burgundy color that they are known for.

TABLE 1: DESCRIPTION OF CRANBERRY PLANT CHARACTERISTICS

| | |
|---|---|
| General characteristics | • Wetlands (bogs, fens→calcium rich wetlands, marshes and shores of rivers/lakes)<br>• Difficult to transplant<br>• Groundcover in wet situations |
| Soil characteristics | • Acid (can grow in very acid conditions)<br>• Can grow in nutritionally poor soil<br>• Moist/wet |
| Vegetative bud characteristics | • 3+ scales overlapping like shingles<br>• Egg shaped |
| Leaf characteristics | • Tiny, glossy, leathery, and simple<br>• Leaf base is rounded, truncate, and symmetrical<br>• Underside is glaucous (waxy/powdery)<br>• Elliptic pinnate veins (widest near the middle), oblong shape<br>• Entire (smooth) leaf edge<br>• One leaf/node<br>• 5-17 mm X 2-8 mm (length x width) |
| Flower Characteristics June-August | • Hermaphroditic (male and female flowers)<br>• Pollinated by insects, self-fertile (self-compatible<br>• Carpels are fused together<br>• 1 pistil /flower<br>• Inferior ovary<br>• Two cycles of petal/sepal like structures<br>• Petals are thin and delicate (pigmented pink or white), sepals are similar to lead coloration<br>• Perianth fused to form a tube/cup/bell shape<br>• Four reflexed petals and anthers resemble cranes bill |
| Fruit Characteristics | • Fleshy berry<br>• Ripen August-October<br>• Bright Red |
| Growth Habit | • Broadleaf evergreen (remains green throughout the winter)<br>• Shrub (woody plant with stems extending from the base)<br>• 0.2 m X 2 m (height x width)<br>• Semi-shade→no shade (woodland) |
| Bark | • Mature-thin and smooth<br>• Brown, gray, red coloration depending on the age of the growth |

**Table 1**: Key phenotypic traits (general to specific) used to correctly identify *V. macrocarpon*. (Rodriguez-saona 2011, Sandler 2008, Burgess 2007).

## II. CROP HISTORY

### A. Breeding & Domestication.

Domestication of *V. macrocarpon* by Caucasians was completed approximately 165 years ago, making it one of the newest domesticated crops produced commercially (Rodriguez-Saona et al. 2011) – although Native Americans bred and traded this crop for thousands of years earlier. At the turn of the nineteenth century farmers in Cape Cod, MA began building dykes and ditches in order to control water levels where the cranberries were already natively growing which led to the earliest cultivation efforts (Hancock et al. 2008). In 1929, the USDA began breeding *V. macrocarpon* for resistance to false bloom disease (Bernadine 2002). Breeding efforts have been focused more recently on consistent uniformity in early maturation and size, consistently high quality, plant productivity and vigor; as well as disease resistance and intensity (Hancock et al. 2008). These efforts are concentrated at the University of Wisconsin, Madison and Rutgers University in New Jersey coupled with their blueberry program (Bernadine 2002). University of Madison, WI has released some hybrids after testing them for vigor, pest resistance, and other important traits.

People question the economic sustainability of growing *V. macrocarpon* commercially due to their numerous challenges that have presented themselves throughout the years. Establishment of the bog requires lots of resources and is time consuming. Bogs are laid out to be approximately 0.46m from the water table (Sandler 2008). Topsoil needs to be removed in order to achieve this and should be leveled with a laser on a slight slope to allow fast drainage of water when needed. Due to the unique habitat of this plant it has succumbed itself to a unique range of problems that have presented themselves. Unless focusing particularly on *V. macrocarpon* there are minimal aids for pests within the bogs. Since the growth habit encourages submersion in water for parts of the season and the roots need constant moisture large bodies of water are often paired with production sites (Sandler 2008). Being a perennial crop reduces the amount of weed control methods that can be utilized and its ground cover growth habit makes it even more difficult. Controlling insects that reduce overall yields is difficult in a perennial cropping system that cannot undergo crop rotation. Chemical measures are commonly utilized mid-season when flooding is discouraged.

The distribution chain for cranberries consists of multiple levels (Table 2). At the top of the distribution chain you will find seed Repositories. The germplasm that is contained within these collections can be either wild or domesticated. Seeds or un-rooted cuttings can be obtained from such places however; cuttings are advisable since the seed crop can vary. Breeders are most commonly the ones to order material from Repositories. Nurseries are then split into two categories retail and wholesale. Retail nurseries are most likely to sell small quantities of plants (e.g. small home gardens) while wholesale nurseries take business from large customers (Cape-Cod Cranberry Association member).

TABLE 2: DISTRIBUTION CHAIN FOR CRANBERRY PRODUCTION

| | |
|---|---|
| Seed Repositories (around the world)<br>-These are responsible for maintaining germplasm (genetic material contained within the DNA structure) | National Germplasm repositories |
| Retail Nurseries (that ship)<br>-All Nurseries are within the United States some in WA, ME, OR, SC, CT, KY, and MO | Cloud Mountain Farm and Nursery, Eastern Plant Specialties, Evermay Nursery, Forest Farm, Park Seed, Quakin' Grass Nursery, Shooting Star Nursery, Stark Bro's Nursery |
| Wholesale Nurseries (authorized buyers only)<br>-All within the United States (MI, MN,OH, ND, and MA) | Alpha Nurseries, INC., Green Value Nursery, Lincoln-Oakes Nurseries, Schumacher, F,W., CO., INC., Sylvan Nursery INC |
| Growers (throughout the U.S.) | Mostly in MA, WI, ME |
| Processors | Oceanspray |
| Consumers | Fresh and processed products. |

**Table 2**: The horticulture distibution chain of *V. macrocarpon*. (n.a., n.d.[2])

## III. PRODUCTION INFORMATION

### A. Current Production Practices.

There are differing types of bogs within cranberry production systems today. One orignates in Cape Cod, Massachusetts (U.S.A.) and naturally forms on peat moss. The other type originates in Plymouth County, Massachusetts (U.S.A.) and is created from old iron ore mining operations (Sandler 2008). The entire ecosystem that surrounds the cranberry bogs is one thing that has yet to change from system to system (Sandler 2008). Consisting of forests, streams, and ponds as well as the actual cranberry fields make up ecosystem that allows cranberry production to be economically viable. Currently a majority (95%) of cranberries are processed into juice, sauce, or added into baked goods. Minimal amounts are sold to the fresh market and an even smaller amount being consumed without some type of cooking (Hancock et al. 2008). Even ones that are sold fresh are generally made into sauce.

Sites for new production are prepped prior to incorporation of *V. macrocarpon*. This includes methods to increase water retention to hold water when bogs are flooded and draining procedures. Vines are obtained as unrooted cuttings and are incorporated into the field with machinery. At this point they are irrigating multiple times per day until roots form and new growth begins. Vines start producing flowers and fruit around the fourth year and are in full swing in year six. Bud development occurs in the year prior to the cropping season (Sandler 2008). The vines need chilling of at least but usually more than 1000 hours before they can initiate bloom. After this requirement is met nine hours of day length and daily temperatures above 5°C are required for optimal flowering response (Sanders 2008).

Pre-emergent herbicides are applied just prior to bud-break which occurs in late March. Nutrient and pH amendments are applied around this same time along with a late water flood to control various pests. Bloom occurs around late May to early June and lasts for approximately three to four weeks. If natural pollinator populations are low or concerning for the crop load it is advised to supply additional pollinators in order to get good fruit set. At this time it is critical to scout for pests, record and manage as necessary in order to reduce crop loss due to pest populations. Pesticides (herbicides, fungicides, and insecticides) are the most popular form at this point in the season since flooding will decrease yield. Harvest occurs late September to early November when a majority of the fields are flooded and mechanically harvested. Hand harvesting only occurs when the product is being sold to the fresh market. After harvest occurs clean-up and winter prep is completed. Pruning, picking up leaf trash, and pH amendments are all part of this process. Upon completion pest pressure will be reduced the following season because of the good sanitation practices.

The production schedule (Table 3) was derived from consists of common practices in Canadian production. Table 3 breaks up the growth stages of the crop into an annual calendar with four main stages (winter prep, pre-bud break, bud-break-berry maturity, and harvest). Plant care throughout the year is first and is highlighted in red. Actions consist of flooding, nutrient additions, and harvesting. Next on the table are soil amenities which mainly consist of soil testing and adding pH adjusters and is highlighted in gold. Pest management takes up a bulk of the table and breaks into three main categories of weed (blue), disease (orange), and insect (purple) strategies. In *V. macrocarpon* production it is common to flood the field at various times to try to control pests without using chemical. To control any and all of these pests it is critical to scout routinely, determine economic thresholds, and map out trouble areas. Removal of trash piles helps reduce all aspects of pest. Some practices are noted as growers' desires or as needed/required and these are denoted by either a single or double asterisks. Approximately every five years a layer of sand is applied to the top of the field once the winter flood has frozen. This practice helps rejuvenate the plants and forces continued upright growth (Bergess 2007)

## TABLE 3: PRODUCTION SCHEDULE FOR CRANBERRIES IN PERENNIAL FIELD PRODUCTION

| December-February | March-late May | Late May-late September | Late September-November |
|---|---|---|---|
| **winter dormancy** | **Spring flood removal to bud-break** | **bud-break to berry maturity** | **Fall harvest** |
| Apply winter flood (avoid low oxygen situations | Apply Sul-Po-Mag for oxygen deficiency injury treatment ** | Frost protect and irrigate as required | Flood Flield/Harvest berries |
| sand bed (rejuvenation) | Pruning ** | Apply Ca/B for optimum fruit set* | Irrigate as needed after harvest |
| | Introduce pollinators at 10% bloom * | Conduct leaf analysis | remove trash piles |
| | Apply pH adjusters (sulfur / lime) | Monitor fruit maturity | prune after harvest * |
| | Monitor and spray pre-emergent herbicides before dormancy breaks | Apply sulfur ** | apply fall fertilizers |
| | Apply l/w (dewberry control *) | Take soil samples | Apply pH adjusters (sulfur / lime) |
| | L/w (fruit rot *) | Monitor and map | Remove trash piles |
| | L/w (cranberry fruit worm & southern mite) | Apply controls ** | Apply pre-emergence controls |
| | | Monitor | Remove trash piles |
| | | Apply fungicides ** | Fall Flood after harvest (cranberry girdler & root weevil) |
| | | Monitor | |
| | | Control ** | |
| | | Summer re-flood (grubs) | |

KEY
- Plant care
- Soil Care
- Weed Management
- Disease Management
- Insect Management

**Table 3**: Annual production schedule containing practices like flooding as pest control as well as the use of pesticides, fungicides, and herbicides *As desired **As needed (Sander 2008, Burgess 2007, n.a., n.d.[3]).

However simplified the production schedule of *V. macrocarpon* seems, it can be very challenging. Bogs require access to a substantial amount of water for multiple reasons, which forces bogs to be near an accessible body of water (lake, river etc.) (Burgess 2007). Water is utilized for mechanical harvest as well as pest and weed control. Since public bodies of water are utilized, chemical control of pests in mid-season can be leached into the waterways and cause other environmental issues. Leeching chemicals into marine ecosystems can throw them out of balance (Burgess 2007).

Managing weeds within the bogs can be difficult since the natural growth habit is a perennial, vining, low-growing plant. Flooding the bogs in spring (also known as late water) helps control weeds during spring growth (Sander, 2008). This allows the vine to bloom before noxious weeds and forces the pollinators to concentrate their efforts *V. macrocarpon*. Normal weed control methods (cultivation, hoeing, and plows) cannot be used which forces growers to use chemical control in the middle of the season when plants cannot tolerate flooding without losing fruit. Insect management occurs along the same timeline as weed management in that flooding occurs along the front and back half of the season with chemical control mid-season. Growers are concerned that the use of organophosphates will soon be regulated in such a manner where they will no longer be able to use them. There currently is not a replacement pesticide which means either the system needs to change or a new insecticide should be formulated (Bergess 2007).

## B. Current Production Statistics.

Over the past four years up to 2014, *V. macrocarpon* production has increased over 50 million kg worldwide (Table 4). Although production in the United States has not increased dramatically, it is clear that Canada is a new, serious competitor in *V. macrocarpon* production. They have nearly doubled their production in the four year span (2011-2014). Chile has not increased their production and remains a small role in overall production. The US provides nearly 2/3 of the market with Canada now producing almost a third and the remainder comes from Chile.

Total production within the United States is broken up by state (Table 5) and measured over two years. Forecasted values for the current year were predicted and were significantly lower than they were in 2013. WI production makes up over half of the US market and seems to be fluctuating in hectares in production. MA is the runner up in *V. macrocarpon* production but is still far behind WI production. The high producing fruit states (OR and WA) are contributing little to this market. Speculation leads us to believe that due to the growing and production requirements it is not economically viable for these states to heavily produce this fruit. Thus it is not surprising to that the highest yields are obtained in WI, MA, and NJ nearing 50 $m^3$ / ha, while in OR and WA yield average around 22 and 33 $m^3$ / ha (Tables 6 and 7). The overall yields ($m^3$/ha) have been slowly increasing over the past ten years as production practices are fine-tuned and are able to maximize yield within a growing season.

There are over 16,000 hectares in production in the U.S.A. averaging yields near 50 $m^3$/ha for U.S.A. *V. macrocarpon* producers (Table 8). The overall production accounts for unsalable berries due to various reasons and further breaks up into fresh market product and processed market product.

TABLE 4: GLOBAL CRANBERRY PRODUCTION (KG X 1000)

| Year | United States | Canada | Chile | Total |
|---|---|---|---|---|
| **2011** | 351,761 | 86,409 | 15,241 | 453,411 |
| **2012** | 360,017 | 133,991 | 16,420 | 510,428 |
| **2013** | 397,816 | 123,049 | 21,092 | 541,957 |
| **2014** | 363,543 | 154,243 | 18,144 | 535,930 |

**Table 4**: Representation of cranberry yield worldwide in thousands of kilograms between 2011 and 2014 (n.a., n.d.[4]).

TABLE 5: US CRANBERRY PRODUCTION FOR 2013 &2014 WITH A PROJECTION FOR 2015 ($m^3$)

| State | 2013 | 2014 | forecasted 2015 |
|---|---|---|---|
| **MA** | 176,841.39 | 197,625.48 | 201,826.2 |
| **NJ** | 52,270.51 | 62,247.25 | 55,850.68 |
| **OR** | 37,233.79 | 47,735.62 | 48,117.51 |
| **WA** | 14,511.63 | 14,893.51 | 17,280.3 |
| **WI** | 574,316.82 | 479,456.59 | 575,281.1 |
| **total US** | **855,174.13** | **801,958.46** | **803,170.9** |

**Table 5:** Representation of cranberry yield throughout the major producing states in the United States in the years of 2013 and 2014 with forecasted 2015 production stats. Yields were measured in barrels and converted to $m^3$ (n.a., n.d.[5]).

TABLE 6: CRANBERRY YIELD ($m^3$/ha) BY STATE & US AVERAGE BETWEEN 2004 AND 2014

| Year | MA | NJ | OR | WA | WI | US |
|---|---|---|---|---|---|---|
| **2004** | 30.69 | 30.60 | 40.27 | 23.59 | 44.75 | 37.35 |
| **2005** | 24.51 | 40.55 | 38.45 | 25.95 | 49.61 | 38.15 |
| **2006** | 32.96 | 36.92 | 40.62 | 15.83 | 53.10 | 42.23 |
| **2007** | 27.63 | 40.41 | 43.24 | 24.42 | 51.33 | 40.58 |
| **2008** | 43.08 | 38.97 | 34.94 | 15.12 | 59.57 | 48.57 |
| **2009** | 32.98 | 42.23 | 37.58 | 22.34 | 51.76 | 42.37 |
| **2010** | 34.33 | 42.77 | 25.08 | 15.00 | 51.90 | 41.71 |
| **2011** | 42.04 | 40.11 | 30.41 | 16.07 | 57.80 | 47.28 |
| **2012** | 38.52 | 43.24 | 32.96 | 19.01 | 57.85 | 47.09 |
| **2013** | 32.67 | 42.65 | 30.67 | 21.09 | 66.72 | 49.87 |
| **2014** | 44.56 | 49.24 | 33.10 | 22.48 | 58.06 | 49.92 |

**Table 6:** Representation of cranberry yields ($m^3$/ha) throughout the US and average of those yields over a ten-year period. These numbers were derived from the current form of measurement of barrels/acre (n.a., n.d.[5]).

TABLE 7: CRANBERRY YIELD (kg/ha) BY STATE & US AVERAGE BETWEEN 2004 AND 2014

| Year | MA | NJ | OR | WA | WI | US |
|---|---|---|---|---|---|---|
| **2004** | 14595.37 | 14550.49 | 19150.11 | 11218.57 | 21281.64 | 17759 |
| **2005** | 11656.1 | 19284.73 | 18286.28 | 12340.43 | 23592.66 | 18140.43 |
| **2006** | 15672.35 | 17557.07 | 19318.39 | 7527.663 | 25253.01 | 20081.25 |
| **2007** | 13136.95 | 19217.42 | 20563.65 | 11611.22 | 24411.62 | 19295.95 |
| **2008** | 20485.12 | 18533.08 | 16614.71 | 7191.106 | 28326.9 | 23099.04 |
| **2009** | 15683.57 | 20081.25 | 17871.19 | 10623.99 | 24613.55 | 20148.56 |
| **2010** | 16323.03 | 20339.28 | 11925.34 | 7135.013 | 24680.86 | 19834.44 |
| **2011** | 19991.5 | 19071.58 | 14460.74 | 7639.849 | 27485.51 | 22482.02 |
| **2012** | 18319.93 | 20563.65 | 15672.35 | 9042.171 | 27507.94 | 22392.27 |
| **2013** | 15537.73 | 20283.18 | 14584.15 | 10029.41 | 31726.13 | 23716.07 |
| **2014** | 21191.89 | 23413.16 | 15739.66 | 10691.3 | 27608.91 | 23738.5 |

**Table 7:** Representation of cranberry yields (kg/ha) throughout the US and average of those over a ten-year period. It should be noted that since barrels are a volumetric measurement weight is approximated and can vary within differing variety, conditions, or situations (n.a., n.d.[5]).

TABLE 8: OVERVIEW OF CRANBERRY PRODUCTION WITHIN THE UNITED STATES AT THE END OF 2014

| State | Area harvested (ha) | Yield ($m^3$/ha) | Total (produced) ($m^3$) | Utilized (produced) ($m^3$) | Fresh (utilized) ($m^3$) | Processed (utilized) ($m^3$) | Price ($/$m^3$) | value of utilized product (1,000 $) |
|---|---|---|---|---|---|---|---|---|
| **MA** | 5,018.11 | 44.56 | 230,754.00 | 223,593.65 | 4,869.03 | 218,724.62 | 3.29 | 80,791.00 |
| **NJ** | 1,214.06 | 49.24 | 64,156.68 | 59,765.00 | * | 59,765.00 | 3.34 | 21,910.00 |
| **OR** | 1,214.06 | 33.10 | 41,148.11 | 40,193.39 | * | 40,193.39 | 2.63 | 11,578.00 |
| **WA** | 687.97 | 22.48 | 15,466.34 | 15,466.34 | 4,964.50 | 10,501.84 | 4.15 | 7,042.00 |
| **WI** | 8,134.19 | 58.06 | 480,697.72 | 479,265.65 | 16,802.94 | 462,462.71 | 2.76 | 144,852.00 |
| **US total** | **16,389.78** | **49.92** | **832,222.84** | **818,284.04** | **26,636.48** | **791,647.56** | **2.97** | **266,173.00** |

**Table 8:** Representation of the US cranberry market at the end of the 2014 season. All measurements were converted into ha, $m^3$, $m^3$/ha or US dollars/ $m^3$. Monetary value was kept as US currency. The (*) indicates no product is being utilized. (n.a., n.d.[5]).

It should be noted that although, overall cranberry statistics do not distinguish between varieties, there are multiple varieties in production today. It is advised that a grower use newer hybrid cultivars to avoid severe pest outbreaks. 'Stevens' is the most popular cultivar today and was developed in 1950. The vine is very productive allowing large, juicy, high quality fruit to emerge mid-season. The cultivar also makes up a majority of the newest beds being planted (Bergess 2002). 'Bergman', 'McFarlin', 'Pilgrim', 'Crowley', and 'Ben Lear' are all produced in similar amounts across the remaining hectares. These cultivars range from early to late ripening and all produce moderate quality (Bergess 2002).

## IV. PROPOSED CROP TRANSFORMATION

### A. Crop Production Change(s) for the Future.

The largest problem by far is the limitation on site selection due to water demands. Bogs already require specific construction practices that allow growers to flood the bogs and maintain a water level when desired. Pest and weed management utilizes this construction. By eliminating damaging factors from the system a grower has more freedom to structure production in order to maximize yields. If a production has to be next to a waterway to allow sufficient amounts of water to be pumped onto the field, why not take it one step further and put production on top of the water source.

By placing *V. macrocarpon* into greenhouse production while utilizing a hydroponic system the sustainability of the cropping system will be increased. A hydroponic system allows a grower to have constant access to a significant amount of water. This allows for a sustainable water source throughout the growing season. This allows growers to avoid disrupting ecosystems (soil and water) when effectively and efficiently producing this crop. The beds should be approximately 1 meter across and either the full length (or width depending on grower preference) of the greenhouse with multiple beds within a greenhouse. The beds will be filled with a growing media that cannot penetrate the holes in the bed that allow water to flow freely. The tops of the bed will also be perforated to allow the submersion of the beds without moving the media. The system should be mechanized in a way where the plant bed can be submerged into the tank to control pest problems and allow adequate water uptake by the plants. Sanitary practices are required to minimalize pest and pathogen pressures. By growing these plants in a soilless media, weed pressures are eliminated and should no longer require control practices, which would allow producers to effectively eliminate environmental concerns for herbicide leeching into public waterways. Multiple aspects of this theory should be tested before being placed into a large scale commercial operation.

Incorporation of aquaponics was not considered a viable option due to the pH requirements of the vines. If/when breeding efforts result in a vine that can withstand a higher pH aquaponics could be considered. *E. coli* is a risk that should be taken into consideration. Natural bogs are flooded with public water that fish live in which would be similar to an aquaponics production system. Threat to human intake could be low however; it might be a battle that is not worth the time or effort.  If the aquatic ecosystem is impacted by human impact it could also make this system unreliable.

## B.  A New Production Schedule for Your Crop.

Crop establishment only varies in the site preparation prior to establishment and the way the vines are established (Table 9).  Vines should be in full production by year six, possibly sooner. Annual production of *V. macrocarpon* will vary slightly with a majority of practices kept (Table 10).  Cuttings will still be obtained and placed into the media bed.  Media beds should be no more than 1 m wide.  This limitation is due to practices that involve human methods (e.g. pruning and harvesting methods).  Different methods of propagation could be experimented with (i.e. raising the water level to meet the cuttings) but irrigation from the top multiple times a day until cuttings are rooted (2-3 weeks) should be utilized first.  Once established watering can be completed with the water tank below.  Pruning will still need to be completed from year to year. However if the growing environment temperature, can be kept above damaging levels but still be low enough to provide the chilling hours required, winter flood can be avoided.  By avoiding winter flood a healthier and stronger crop can be produced and in turn be higher yielding. Sanding can also be avoided since it would slip through the media and no is no longer useful. Application of Sul-Po-Mag would no longer be needed if plants are no longer subjected to a winter flood and do not experience oxygen deficiency.  Herbicides would no longer be useful if a sanitary environment is kept.  Pest and pathogen management will proceed as needed.  Flooding can still be an effective tool in springtime for management strategies and also in the fall for efficient harvest.  Water tests to measure pH levels will have to be monitored carefully and will take the place of soil tests.

Since this particular crop is a perennial the life cycle is set.  Bud initiation occurs in July of the year prior to fruit set which makes acceleration of this crop difficult.  Initiation occurs when days start to become short and require a chilling period for fruit set.  The whole cycle takes 16 months. The buds develop into the fall until freezing occurs and they go dormant (n.a., n.d.[6]). This allows the plant to flower early in the spring giving the fruit the entire summer to develop once pollination has occurred. Bloom starts at the beginning of June and lasts for a month. Fruit set occurs three weeks after pollination. 80 days after bloom are usually required for vines to produce fully matured fruits (n.a., n.d.[6]).

TABLE 9: BUILDING PRODUCTION AND FIRST YEAR ESTABLISHMENT OF CRANBERRY VINES

| **Building year** | | **Establishment year** | | | |
|---|---|---|---|---|---|
| **January-April** | **May-November** | **December-February** | **March-April** | **May-September** | **October-March** |
| No activity | Build greenhouse | Run cycles to ensure working order | Obtain cuttings | Insert cuttings into media | Prune as needed |
| | Bed construction | | Insert media into the bed | Water 2-3 times per day until cuttings are rooted | Chilling period |
| | Add hydroponic systems | | | Water hydroponically with the bed | |

**Table 9**: Time scale for greenhouse construction (depending on the size) in preparation of vine establishment. Establishment year is broken up into blocks of time and tasks are listed in the block of time in which they should be completed.

TABLE 10: NEW ANNUAL PRODUCTION SCHEDULE FOR CRANBERRY PRODUCTION IN HYDROPONIC CONDITIONS

| December-February | March-late May | Late May-late September | Late September-November |
|---|---|---|---|
| **winter dormancy** | **Spring flood removal to bud-break** | **bud-break to berry maturity** | **Fall harvest** |
| **Apply winter flood (avoid low oxygen situations** | **Apply Sul-Po-Mag for oxygen deficiency injury treatment **** | Frost protect and irrigate as required | Flood field/Harvest berries |
| **sand bed (rejuvenation)** | Pruning ** | Apply Ca/B for optimum fruit set* | Irrigate as needed after harvest |
| | Introduce pollinators at 10% bloom * | Conduct leaf analysis | remove trash piles |
| | Apply pH adjusters (sulfur / lime) | Monitor fruit maturity | prune after harvest * |
| | **Monitor and spray pre-emergent herbicides before dormancy breaks** | Apply sulfur ** | apply fall fertilizers |
| | **Apply l/w (dewberry control *)** | **~~Take soil samples~~** | Apply pH adjusters (sulfur / lime) |
| | L/w (fruit rot *) | **Monitor and map** | **Remove trash piles** |
| | L/w (cranberry fruit worm & southern mite) | **Apply controls **** | **Apply pre-emergence controls** |
| KEY<br>Plant care<br>Soil Care<br>Weed Management<br>Disease Management<br>Insect Management | | Monitor | Remove trash piles |
| | | Apply fungicides ** | Fall Flood after harvest (cranberry girdler & root weevil) |
| | | Monitor | |
| | | Control ** | |
| | | Summer re-flood (grubs) | |

**Table 10**: Annual production schedule containing practices like flooding as pest control as well as the use of pesticides, fungicides, and herbicides *As desired **As needed (Sander 2008, Burgess 2007, n.a., n.d.[3]).

## C. The New Crop Ideotype.

The new crop ideotype will aid in the successful transition of *V. macrocarpon* production from the field into hydroponic conditions. The hydroponic cranberry ideotype has to include improvement of the vine to make it profitable to be grown hydroponically. Since proposing to move production into hydroponic systems the vines sensitivity to changes in pH should be considered. Hydroponic production is more difficult than field production because you lack soil that acts as a natural buffer. Breeding efforts should include those of making more resilient plant material to pH changes. These can be problematic if a careful eye is not kept on the pH of the system. Toxicities or deficiencies can occur more frequently when grown in a hydroponic environment when nutrient levels are not managed properly or the pH gets out of control.

Key traits included in the hydroponic cranberry ideotype are; uniformity of berry maturation and size, ability to consistently produce high quality berries, plant productivity and vigor, and disease resistance/tolerance. Ability of the plant to produce good stands in hydroponic production is required. Most of these traits can be seen as improved on since breeding efforts began.

Uniformity in size, color, and maturation time will aid greenhouse growers in harvesting strategies. Breeding efforts focused on size and maturation time will allow producers to mechanize harvests within the greenhouse. Color is important for consumers that are purchasing the fresh product. However, most often growers do not have direct contact with the consumers. A majority of the harvested crop gets shipped to Oceanspray™ to be processed into various products. Uniformity for all of these phenotypic traits will make your product more appealing to this company. A crop that lacks these traits can be turned away or be bought at a lower price since there is only one producer to sell to.

Plant vigor and productivity is important in any operation but even more so in a greenhouse when time and space is money. If plants do not grow vigorously in greenhouse operations, profitability will decrease. If profits are not there growers will not adopt this practice. This might be an issue over the first few years as the plants are getting established. The vines might not be able to root well in the media. By taking six years to reach full production these traits will not be known unless tests are done both in the field and in greenhouses to measure the productivity and vigor.

A different ideotype, however, would been needed in order to transition production of the crop into aquaponics. All of the same phenotypic traits would be desired as in the hydroponic ideotype. Tolerance to higher pH values (around 7) in order to allow fish to survive and be able to be part of the ecosystem would be necessary in order to make the system work. This might not be possible since other members of this genus also require lower pH values (e.g. blueberries). Genetic material in order for the plant to withstand a higher pH might to be available through traditional breeding methods. It might not be beneficial in the long run to make this plant tolerant to a higher pH. Creating a variety that is tolerant of these pH levels could inhibit their ability to be used as a preservative or have other effects on yield quality.

Also with this type of system since aquaponics production is relatively new many avenues have not been researched yet that might be useful. Most commonly USDA and FDA (United States Department of Agriculture and Food and Drug Administration) see issues with animal fecal matter and food since food borne pathogen outbreaks have been increasing in recent years. Surprisingly they have not regulated the use of public water in bogs with this mind set. Current cranberry production use water from sources that harbor fish, thus fecal matter. There have been no known pathogenic outbreaks associated with cranberries. Caution should still be taken when this method is being used to produce this crop. In order to use the same system as in the hydroponic method listed first, proof that cranberries would not contain *E. coli* in all cases. This would consist of multiple years of testing to prove that it could not happen. Even so, government agencies might regulate against it in order to protect populations. This can complicate production, forcing it to be not economical to continue on this route.

Regardless of the ideotype (hydroponic or aquaponics) there will be challenges within the system that need to be overcome. For one, this crop is perennial. Producers get one crop per year and need a chilling period in between production to obtain a crop the next season. This requires a grower to maintain this crop in the greenhouse in the winter when it is not producing a harvestable yield. This takes money, time and effort. This is an important consideration because when they are grown outside they take no maintenance in the winter months while they are dormant. This can cause the ideotype to be less desirable. However, by growing them in greenhouse production you can eliminate some of the costs that are associated with cranberry production. Plant injury due to low oxygen levels during the winter months will not be seen. Avoiding such injuries could raise yield levels significantly, making the winter maintenance worth the trouble.

Not many perennial crops are seen in greenhouse production, especially not ones that produce one large harvest per year. This can mean that it is not economically viable to do so. This is also a specialty crop that although has demand, it has a limit on the premium that people are willing to pay for it. The maintenance on such a system can be costly throughout production. Since there is minimal work during the season except for harvests it might require less people to operate such a production system. Since weed pressures will be controlled by using a growing media; management strategies do not have to be implemented throughout the seasons. Scouting for pests and pathogens will allow a producer to control them at a lower level.

Establishment of *V. macrocarpon* requires a lot of upfront costs. Growers will not even start seeing an income until the four year, with the crop being in full production by the six year. This limits the amount of people who can even start up an operation like this. A grower would have to have alternate sources of income for the first six years just to keep the operation running. This will discourage some people from moving into this venue of production, however, this does lower the amount of work needed in the future. A grower would save money be avoiding winter floods and sanding, herbicide control measures, and frost protection.

One of the major obstacles in moving production into hydroponic systems is that new tools will need to be developed. Tools will be needed insert the vines into the growing bed during the establishment phase, in an efficient manner. Tools will also be needed to mechanize harvesting in water in greenhouses. Tractors and prior methods will not likely be used since space is limited in greenhouses. Being a specialty crop this means that tools will be developed specifically for hydroponic cranberry production. Since this crop is not one of our major crops in the United States it will be difficult to find people to develop such a specialized tool for an economical price. Specialized tools come with a pretty hefty price tag.

The largest part of moving *V. macrocarpon* production into specifically a hydroponic setting is to conserve aquatic ecosystems. Chemicals that are used to control pests are being leached into waterways and are having negative effects on aquatic life. This is seen because producers use public water (lakes, rivers, ponds, etc.) as a source for various methods of production. Moving this crop into indoor production where the beds are on top of water tables, growers have constant access to extravagant amounts of water in order to economically produce their crop. Water would not be leeched into the environment and would need to be obtained to fill the beds as it evaporates or gets used by the plants. Chemical infused water would rarely leave the system once it was established in production.

Winter flooding of the crop to avoid frost damage and control insects can be avoided when moved into hydroponic production in greenhouses. While it keeps the plants alive and keeps pest populations at reasonable levels, it by far does not keep the plants healthy. Over the course of the winter they are subjected to low oxygen levels and most often need to be treated with a chemical to offset the damage that was caused. Greenhouses provide a controlled environment that can be kept above damaging temperature levels while allowing the plant to receive the right amount of chilling hours to break dormancy in the spring. Pest levels can be controlled in the spring with a light flooding if populations are concerning. Since temperature levels will be below freezing populations should not increase while the plant is dormant.

Hydroponic production that utilizes water tables below a grow bed, will allow growers to utilize water as a harvesting tool. Since this production practice is new, tools will have to be developed to aid in harvesting. Ideally beds will be able to be submerged into the water table they are sitting above. Tools will then be used to knock the berries from the vines and will float to the top of the water bed to be harvested.

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## VI. LITERATURE CITED

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